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[redacted]

MLT-3164-L-5837
1 February 1971

Officer-in-Charge
USA Communication Service Group
Post Office Box 72
NAS Moffett Field, California 94035

Subject: Contract [redacted]

Gentlemen:

With reference to subject contract Technical Requirements paragraph 3.1.12, the attached report prepared by the [redacted] Senior Technical Staff, and based in part upon data published by nationally known authorities and groups practicing in the areas of ultraviolet radiation and its effects, is submitted as certification that personnel properly operating the [redacted] Split Format Light Table MLT-1540 will incur no medical damage from table light source ultraviolet radiation as defined by the safe limits of exposure in data submitted to [redacted] by the customer. As the radiation levels involved are significantly below the range of measurement of any available instrumentation such as the Cary 14 Recording Spectrophotometer, the report utilizes published data relating to the characteristics of the phosphors, gases and glass used in the fluorescent tubes, and the transmission of the various attenuating glasses and diffuser of the table for harmful ultraviolet radiation. The report concludes that the resulting ultraviolet radiation exposure from the light table in expected daily use is substantially below that which would cause medical damage as defined in "UV Exposure Criteria", dated 10-4-70.

Very truly yours

[redacted]

Supervisor, Contract Administration

WGB:j

Attachment: as stated

STAT [redacted]

The Absence of Cornea-Damage Ultraviolet Irradiation

in the [redacted] STAT

Split Format Light Table MLT-1540

Contract [redacted] STAT

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Summary

This report presents an analysis, based in part on data published by nationally known authorities and groups practicing in the areas of ultraviolet radiation and its effects, to verify that the [redacted] Split Format Light Table MLT-1540 properly operated will not produce ultraviolet radiation in excess of that defined by the safe limits of exposure in data submitted to [redacted] by the customer, (Reference 1). This analytical technique supported by measured data is necessary for verification since the radiation levels involved are significantly below the range of measurement of any available instrumentation such as the Cary 14 Spectrophotometer. The latter is capable of radiation measurements in the ultraviolet range of interest to optical densities of no more than 3.3. This report substantiates that the basic table materials between the observers eye and the table fluorescent lamp sources attenuate harmful ultraviolet radiation by optical densities of at least 4.8, and hence means other than direct measurement are required for verification.

This report concludes that the resultant harmful ultraviolet radiation exposure to the observer from the light table in anticipated daily use is in the worst case less than 1% of that permitted by Reference 1.

Eye Irradiation Calculation Model of the Modular Light Table (MLT)

The theoretical MLT illumination model for irradiation calculation to determine if there is sufficient ultraviolet radiation to produce corneal damage is hypothesized to represent an extreme worst case condition, i.e., to produce considerably greater ultraviolet irradiation at the observers eye than could ever occur in practice, thereby insuring the safety of the calculation manifold times. The radiation source is taken as a single flat continuous fluorescent lamp surface directly beneath and parallel to the table's diffuser surface and equal in area to the illuminated viewing surface. Immediately above the diffuser rests the table top viewing glass. Detailed spectral transmission models for all three elements are provided below. It is assumed for the worst case that the fluorescent lamp surface brightness is equal to the maximum initial brightness of any surface of a single fluorescent lamp in the MLT and further that the total light emitted by this hypothetical lamp surface radiates all its energy to the diffuser without scattering or reflective losses within the interior of the table.

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Maximum Allowable Ultraviolet Irradiation

The maximum allowable ultraviolet exposure per unit area at the observers cornea is given in Reference 1 and may be expressed as the following equation,

$$T_{(sec)} \sum_{\lambda=205}^{\lambda=325} H_{\lambda} W_{\lambda} T_{\lambda} \leq 5.7 \times 10^{-4} \text{ joules/cm}^2 \qquad (1)$$

where

H_{λ} ≡ Source corneal irradiance in a given 10 nm waveband expressed in watts/cm² for W_{λ} and T_{λ} equal to unity.

W_{λ} ≡ Relative corneal damage efficiency as per Table 4.1-1A of Reference 1.

T_{λ} ≡ Transmittance per waveband of all attenuators placed between source and observer's eye.

This represents 1/6th the damage threshold value calculated in ℙ 4.1.1.2 of Reference 1 as stipulated in the Chart Paragraph.

A worst case estimate of expected daily use is made as follows: Assume an 8 hour working day 1/3 of which involves microscopic viewing, 1/3 unaided viewing of film of average density of 0.8 or 16% transmission, and 1/3 direct exposure to table illumination at full brightness. Assume further that in the latter two cases the eye is 10 inches from the table top centered at one of the two available lighted viewing surfaces. The microscope will not transmit any detectable ultraviolet irradiation below 3400Å due to the relatively long total optical path through the various glass elements; (this will become more apparent below when glass transmission calculations are made). For example, the normal visual transmission of microscopes of the class employed with the MLT is 10 to 12% and provides an idea of optimumly minimized microscope attenuation in the desired viewing region. On this basis the total worst case exposure time to full brightness irradiation is (1.16)8/3 hours or 11,200 seconds.

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To calculate the total allowable worst case irradiation we require the irradiation geometry factor. The viewing surface is a lambertian diffuser because of the diffuser material directly below the glass plate, and can be approximated as a circular area 21 inches in diameter thus having about the same area as a single table top section of about 16 by 22 inches. The irradiation geometry factor is given by $\pi \sin^2\theta$ where θ is the half angle subtended by the observers eye at the circumference of the viewing area. For our case this is 46.5° and the irradiation geometry factor calculates to 1.65. Thus the maximum allowable irradiation at the eye in units of watts/cm², $H_\lambda = 1.65R_\lambda$ where R_λ is the maximum allowable table top radiance in watts/cm²/steradian*. With this substitution for H_λ in Eq. (1) and including the total worst case exposure time of 11,200 seconds, we have for the total allowable corneal irradiance,

$$\sum_{\lambda=205}^{\lambda=325} R_\lambda W_\lambda T_\lambda \leq 31 \text{ nanowatts/cm}^2 \qquad (2)$$

Table Top Viewing Glass Spectral Transmission

The table top viewing glass is a twin grind heavy polished plate glass, 0.375 inch (9.5mm) thick, and as per Federal Specification DD-G-451C. Its composite materials are thereby controlled under the specification to be natural silica sand and a mixture of two or more alkaline salts such as soda, lime, or potash. The glass was produced to this specification [redacted] and is termed as their heavy duty parallel-o-plate. This material is used extensively architecturally and its composition and spectral transmission as such are not as closely controlled as optical filter glasses or provided or measured by the manufacturer. There are, however, published spectral data for other glasses of this same composition, categorically termed window glass.

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Exhibit 1 reproduced from Reference 2 depicts the transmission of typical window glass composition materials. As noted in the text of Exhibit 1 window glasses in thicknesses of 2 mm or more are practically opaque to ultraviolet of wavelengths shorter than

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* with W_λ and T_λ both equal to unity as in the definition of H_λ.

3000Å. The material used in the MLT table is nearly five times this thickness or 9.5mm. However, due to the extremely small total allowable corneal irradiation permitted by Eq. (2) it becomes necessary to verify quantitatively the quoted phrase "practically" opaque to ultraviolet of wavelengths shorter than 3000Å". Examination of Figure 4 of Exhibit 1 indicates that for wavelengths below 3125Å the curve data is insufficiently accurate for use in such a sensitive calculation. The author of Reference 2, Dr. Koller a nationally recognized authority on ultraviolet irradiation, calculates in Table 1 the absorption coefficients of window glass down to wavelengths of 3150Å. Beyond this point shorter wavelength data to construct our glass model will be extrapolated from Exhibits 2 reproduced from Reference 3.

In Exhibits 2 note that curve number 10 identified in Table 1 is shown as transmittance data in Figure 1. This data is for a glass microscope slide which is essentially a thin (1.3 mm) plate glass of composition similar to window glass with the possible exceptions of the additions of crown and borosilicate glass materials for index of refraction control, and to provide a glass structure which is readily amenable to ultrafine optical flatness polishing. The ultraviolet transmission of borosilicate or crown type glasses is generally significantly greater than the window or lime, potash or soda glasses; (see, for example, Exhibit 3 reproduced from Reference 4 which indicates the ultraviolet transmission of American Optical crown glass, 1.68 mm thick, which could be used as microscope glass).

Ultraviolet data below 3150Å can be derived from the glass microscope slide data through application of Bouger's law of absorption which is given as

$$\text{Transmission} = (1-r)^2\, e^{-\alpha t} \qquad (3)$$

where

$t \equiv$ Glass thickness traversed by the radiation

$\alpha \equiv$ Absorption coefficient

$r \equiv$ Glass-air reflection coefficient.

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Table 1 below is data calculated from the glass microscope transmission curve 10 of Exhibit 2.

% Transmission	λ (Å)
$0 \leq 0.05$	2740
5	2940
12	3000
35	3100
48	3150
60	3200

Table 1. Microscope Slide Glass Transmission (1.3 mm thick)

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Note that as explained [redacted] the zero point datum plotted on curve 10 is taken to mean a transmission $\leq$ 0.05% and represents the zero reading of the Cary 14 Recording Spectrophotometer; this occurs at approximately 2740Å. Additionally spectral data beyond the 3200Å 10 nm waveband is not considered since the relative damage efficiency is zero in this region, (Reference 1).

Entering the data of Table 1 (Exhibit 1) at 3150 and 3200Å in Bouger's law, Eq. (3), the window glass transmittances at these wavelengths are calculated for a 1.3 mm thickness to be 23 and 35% respectively. Comparing these to microscope glass transmittances at the same wavelengths, it is seen that window glass transmissions are 48 and 58% respectively of that of microscope glass. Therefore, in the region of wavelengths shorter than 3150Å, as a worst case assumption we shall assume that window glass transmission is 48% that of microscope glass. This assumption is of course pessimistic in that window glass transmission will clearly decrease at a much faster differential rate than 48% for decreasing wavelengths.

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Table 2 represents our transmission model for window glass of 1.3 mm thickness and includes the therefrom derived values of the absorption coefficient which are valid for any thickness described by Bouger's law.

% Transmission	λ (Å)	$\alpha\ cm^{-1}$
0	λ < 2740	∞
$\leq$ 0.025	2740	$\geq$ 63.7
2.5	2940	28.3
6	3000	21.6
17	3100	13.6
23	3150	11.4
36	3200	7.9

Table 2. Table Top Viewing Glass Material Spectral Response Model(1.3mm Thickness)

In Table 3, this absorption coefficient has been used to calculate the ultraviolet transmissions for a 9.5 mm glass thickness representing the table top viewing glass. It is readily discernible that at wavelengths 3000Å and below, ultraviolet attenuation is extremely great and the material is virtually opaque. For wavelengths 2740 and less the transmission is taken to be absolute zero.

% Transmission	λ (Å)
0	λ < 2740
0	2740
0	2940
1.2×10^{-7}	3000
.00025	3100
.002	3150
.055	3200

Table 3. Table Top Viewing Glass Spectral Response Model (9.5 mm Thickness)

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Diffuser Spectral Transmission

The diffuser material used in the MLT is type W-2477 plexiglas, a trade name for a blend of acrylic plastics, 0.125-inch (3.18mm) thick, manufactured by Rohm and Haas. This is a white translucent material measured by [redacted] to have a diffuse transmission of 40% in the visible region. Detailed spectral data is not available for this particular commercial material but however there is sufficient published data on ultraviolet transmission of the plexiglas family for us to construct a worst case transmission model. Referring to Exhibit 4 of Reference 5 Figures 42 through 47, it is indicated that although plexiglas ultraviolet transmission varies widely with detailed composition (note the absorption bands), that for thicknesses similar to the MLT diffuser there is indicated "zero" transmission at or below 3250Å. Based on a relative comparison of these curves, the window glass curve of Exhibit 1, and curve 12 for 6.35 mm thick plexiglas (Exhibit 2), it is clear that there is certainly less transmission below 3250Å in plexiglas than in the plate glass used for the table viewing surface or even the microscope glass. Since the 9.5 mm thick plate glass has a visible transmission (including Fresnel losses) of about 80% or twice the diffuser transmission we can assume in the worst case that the diffuser ultraviolet transmission is as great as one-half that of the glass at wavelengths 3200Å and below. This reasoning enables us to construct the model of Table 4.

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% Transmission	λ (Å)
0	$\lambda \leq 2940$
0.6×10^{-7}	3000
.00013	3100
.001	3150
.028	3200

Table 4. Diffuser Spectral Response Model (Plexiglas 3.18 mm Thick)

Table Top Viewing Glass-Diffuser Combined Spectral Transmission

The combined spectral transmission of the serially arranged diffuser and table top viewing glass is given as the product of the individual transmissions at each wavelength, and presented in Table 5. Transmittance has been taken as absolute zero for wavelengths at and below 2940Å since the transmittance at 3000Å is down 14 orders of magnitude and would require an unreasonably bright ultraviolet source to provide meaningful contributions to the nanowatt/cm² value given in Eq. (2).

% Transmission	λ (Å)
0	$\lambda \leq 2940$
$.72 \times 10^{-14}$	3000
3.15×10^{-8}	3100
2.00×10^{-6}	3150
1.54×10^{-3}	3200

Table 5. Glass-Diffuser Combined Spectral Response Model

The transmission data of Table 5 represents T_λ of Eqs. (1) and (2) expressed in decimal form. Referring to Table 4.1-1A of Reference 1 it is seen that only the last three wavebands can contribute to produce corneal damage through the glass-diffuser combination. Entering the relative efficiency factors, W_λ, for these into Eq. (2) we have,

$$0.36\, R_{300} T_{300} + 0.2\, R_{310} T_{310} + 0.011\, R_{320} T_{320} \leq 31 \text{ nanowatts/cm}^2 \quad (4)$$

where the table top radiance and total model transmission are evaluated at the center of the three 10 nm wavebands. Substituting for the latter from Table 5 we have for our worst case damage protection constraint on R_λ,

$$.26 \times 10^{-16} R_{300} + .65 \times 10^{-10} R_{310} + .17 \times 10^{-6} R_{320} \leq 31 \text{ nanowatts/cm}^2 \quad (5)$$

R_λ in this context is the unattenuated corneal irradiation of the fluorescent source.

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Fluorescent Lamp Surface Radiation Model

In this section we shall obtain the worst case values for R_λ, the maximum allowable table top radiance in watts/cm²/steradian, necessary for substitution into Eq. (5). R_λ is equal to the maximum allowable table top radiance only if W_λ and T_λ are both taken equal to unity as explained earlier. When values from the table of Reference 1 for W_λ and values of Table 5 for T_λ are substituted into Eq. (5), R_λ becomes the maximum allowable radiance of the fluorescent lamp source of our MLT irradiation calculation model.

The fluorescent lamps used in the MLT are manufactured by Voltarc Tubes Co. to STAT [redacted] specifications special design. This design produces a compact fluorescent lamp of extremely high (6000 ft.-lamberts) initial brightness with relatively low power consumption (20 watts). This performance is primarily achieved through design of the electrical discharge configuration within the lamp and secondly through reduction of the visible light self-absorption of the phosphor. In all other respects it is similar to the ordinary household or commercial fluorescent lamps.

The glass envelope utilized in the lamp is made from a potash soda lead glass STAT [redacted] and bearing their identification number 0010. The glass wall thickness is .055" ±.003" or nominally 1.4 mm thick. The ultraviolet transmission of this glass is similar to the lighted viewing surface glass discussed above and to glasses used in commercial fluorescent lamps.

The lamp's internal gaseous environment is also similar to household or commercial fluorescent lamps. There is a small amount of mercury which at lamp operating temperature produces the customary extremely low mercury vapor pressure of 6-10 microns. A small amount of inert argon gas is also mixed with the mercury. The electrical discharge converts approximately 60% of the total energy consumed by the lamp into ultraviolet radiation concentrated at the 2537Å mercury line. About 99% of this line radiation is absorbed by the phosphor coating and converted to radiation

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of higher wavelength most of which is visible, (Reference 3, pgs. 263-264). Thus the fraction of total energy contributing to harmful ultraviolet radiation is very small being in the range of less than 1 to 2%. We shall reconcile this number later with our chosen values for the fluorescent surface radiance.

The lamp phosphor is primarily calcium halo phosphate mixed with small amounts of other phosphors and activators to produce a nominal blackbody color temperature (CCT) of 5000°K, corresponding in commercial-household lamp terminology to a modified cool white, and to reduce the phosphor self-absorption for visible radiation to increase lamp surface brightness. Calcium halo phosphates are standard for white fluorescent lamps (Reference 2, pg. 262) and for this lamp were manufactured by the Chemical and Metallurgical Division of Sylvania Electronics. The lamp color temperature specification is 5000 ± 500°K which converts to a blackbody peak wavelength range of approximately 5270Å to 6450Å, as calculated by Wien's displacement law. MLT color temperature tests have indicated that the apparent source color temperature as measured at the table top is at the high end of the color temperature range, or corresponds to a wavelength peak lower than the 5800Å peak of the cool white lamp spectrum depicted in Exhibit 5, (reproduced from Reference 6). This exhibit also indicates the values of radiant power generated in the ultraviolet region to approximately 3000Å. The worst case (greatest) radiation between 3000 and 3200Å is seen to occur for the lower color temperature (~ 4750°K) deluxe cool white lamp. This is also borne out by an alternate data source (Reference 7, page 40) which indicates that radiation is greater in the lower ultraviolet wavelengths for the deluxe cool white lamp. Hence the deluxe cool white fluorescent lamp represents more harmful ultraviolet radiation than would be expected from the modified cool white lamp of the MLT, and its data shall therefore be used in our worst case calculation.

The deluxe cool white ultraviolet radiation data of Reference 7 pertains to a 40-watt commercial fluorescent lamp. As such it consumes twice the power of the MLT lamps and would in this respect alone produce about twice the harmful ultraviolet radiation. To further verify this point a comparison of the fluorescent energy conversion efficiencies can be made. Reference 7 states that such a lamp will produce 1840 lumens or 46 lumens/watt. The MLT fluorescent lamp total surface area, represented by a cylinder 20 inches long of 5/8 inch diameter, is .273 ft^2. For an initial brightness of 6000 ft.-lamberts this converts to 1635 lumens ($\frac{6000}{\pi} \times \frac{\pi}{.273}$), or a luminous efficiency of nearly 82 lumens/watt. Thus, since the MLT lamp converts ultraviolet energy to visible radiation at a factor of nearly 1.8 times greater than the 40-watt commercial lamp it would be expected that the same reasoning can be extrapolated to the ultraviolet region. Hence our use of the 40-watt lamp radiation value is conservative by a factor of at least 1.8 based on total watts consumed. (This conservative estimate is independent of the relationship of the two lamps surface areas. The surface area of the 40-watt lamp being considered, which is a 4-foot long 1.5-inch diameter lamp, is nearly six times that of the MLT lamp.)

The 40-watt deluxe cool white lamp total radiation data is given in 10 nm waveband intervals in Reference 6 as,

Waveband nm	290-300	300-310	310-320	320-340
watts	.003	.012	.062	.089

Table 6. Total Harmful Ultraviolet Radiation from a 40-watt Deluxe Cool White Fluorescent Lamp

(After Reference 6)

These numbers represent the total radiation emitted over the lamp's entire surface area. To reconcile the total ultraviolet radiation provided for this lamp in Reference 6 with our 1 to 2% number estimated above, we note that Reference 6 specified a total of .472 watt radiation in the entire ultraviolet region (4000Å and below). This represents 1.2% and 2.4% of the 40-watt and our 20-watt lamp power consumptions respectively. In the MLT table, of course, not all the lamp surface radiation is contributed to the diffuser since nearly one-half the lamp surface area radiates to the rear striking a white highly-reflective surface which returns some of the radiation to the lamp itself. Thus a portion of the lamp serves to shadow and reabsorb radiation. This worst case analysis however will neglect this absorption and assume that it too reaches the diffuser. Our irradiation calculation model assumes a flat fluorescent source equal to that of the table top viewing surface. This however is not the case since the total surface area of the twelve lamps per viewing side themselves constitute approximately 35% more surface area. All other factors being equal this 35% underestimate in our model may be considered to correspond to and cancel the lamp shadow effect mentioned above.

To convert the total radiation numbers of Table to radiance (watts/cm²/steradian) we use the relationship

$$R_{\lambda} = \frac{\text{watts per 10 nm waveband at } \lambda}{\text{lamp surface area} \times \pi} \qquad (6)$$

which holds for a diffuse radiator such as the lamp phosphor. Table 7 indicates the results of these calculations.

Waveband nm	290-300	300-310	310-320	320-340
Radiance, watts/cm²/steradian	0.4×10^{-5}	1.5×10^{-5}	7.75×10^{-5}	1.11×10^{-4}

Table 7. Fluorescent Lamp Surface Harmful Ultraviolet Radiation Model

Corneal Irradiation Calculation

We now must select values for the three radiances of Eq. (5) from Table 7. For R_{300} we choose the higher available radiance value at 300 nm, namely the one corresponding to the 300-310 nm waveband since the predominant radiation in the 295-305 nm damage interval is the 3022Å mercury line. For R_{310} we choose 310-320 nm band since the 3131Å mercury line is the greatest contributer to the 305-315 damage waveband. And finally, for R_{320} we choose the 320-340 nm radiation band value. This last choice is again a worst case number since in the damage band 315-325 nm there are no principal mercury lines and the radiation is primarily blackbody-like, while the data shown in the 320-340 nm band represents the contribution of the 3140Å mercury line. With these substitutions we find that, the left hand side of Eq. (5), the worst case corneal irradiation at the observers eye is .02 nanowatts/cm^2 or 1500 times below the maximum allowable irradiation of 31 nanowatts/cm^2.

WINDOW GLASS

Ordinary window glass in thickness of 2 mm or more is practically opaque to ultraviolet of wavelengths shorter than 3000 Å. A common thickness for home windows is about 0.1 inch. Thus an ordinary window pane, although it admits most of the incident visible radiation

TABLE 1

ABSORPTION COEFFICIENT OF WINDOW GLASS*

Wavelength in Å	α cm^{-1}
3150	11.4
3200	7.9
3400	1.7
3600	0.54

* Calculated from data supplied by Pittsburgh Plate Glass Co.

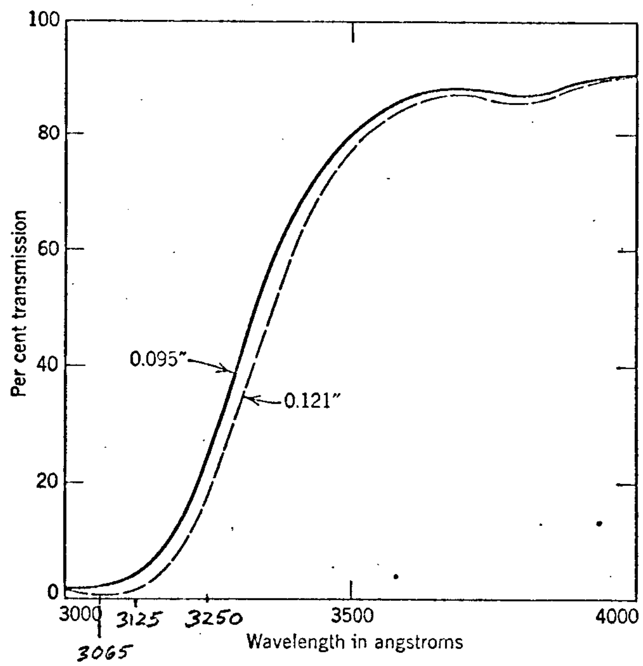

Fig. 4. Transmission for two thicknesses of window glass. (Data supplied courtesy of Pittsburgh Plate Glass Co.)

Exhibit 1

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Table I. Solids and Glasses Traced in Figs. 1 and 2

Curve number	Description	Thickness (mm)	Remarks
1	Suprasil disk	1.59	Ref. 4
2	Optosil plate	1.59	Ref. 4
3	Optosil plate	6.35	Ref. 4
4	ADP	23.0	Light ⊥ to opt. axis
5	ADP	43.5	Light approx. ⊥ to opt. axis
6	Calcite	11	Light approx. 45° to opt. axis
7	Schott BG-24	1.0	Ref. 3, but approximately corrected for reflection loss assuming constant n
8	Schott UG-5	1	
9	Schott UG-11	1	
10	Glass microscope slide	1.3	Braun #48299
11	Kel-F 81	1	
12	Plexiglas	6.35	
13	Four Suprasil disks	4 × 1.59	Water coupled
14	Corning C.S. 9-54	0.50	1/4 stock thick
15	Corning C.S. 9-54	2	Ref. 2
16	Corning C.S. 7-54	3.0	
17	Corning C.S. 9-53	0.50	1/4 stock thick
18	Corning C.S. 9-53	2	Ref. 2
19	Schott UG-2	2	

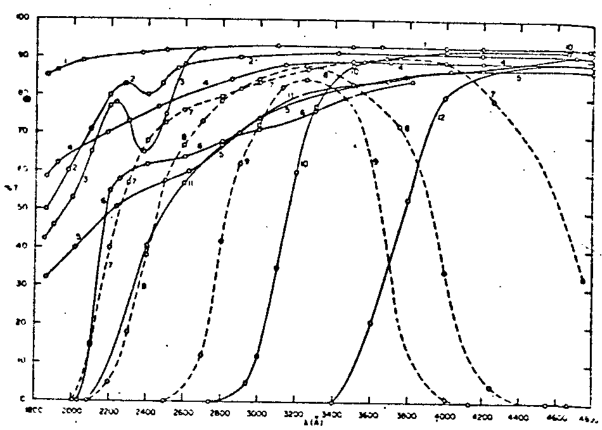

Fig. 1. Transmittances of glasses and crystalline solids. See Fig. 2 and Table I.

In this paper, transmission values are given in terms of percentage transmittance $T_\lambda = 100\ I/I_0$, where I_0 and I are the intensities of light incident on and emerging from the sample. Fresnel reflection losses are therefore included in T_λ. The tracings were done on the Cary 14 recording spectrophotometer. The zero indicated on the Cary 14 is taken here to mean transmission $\leq 0.05\%$.

Exhibit 2

TRANSMISSION OF COLORED GLASSES

If I_o is the intensity of radiation entering a layer of some medium and I the intensity reaching the opposite surface, the ratio I/I_o is called the transmittance. In practice the ratio of intensity of radiation passing through a glass sample to that incident on its surface is often measured and plotted as transmission. The transmission is the result of two factors, the transmittance of the glass and the losses by reflection. These losses amount to about 4% for each glass-air surface; the transmission of a sample is about 92% of its transmittance. Since the reflection losses differ slightly with different samples, the correction is often determined and applied when the transmission is measured. Values which are thus corrected are marked * at the head of the column.

In order to obtain the transmittance for thicknesses other than those listed it is convenient to transform the tabular values to terms of βt in the equation $I/I_o = \epsilon^{\beta t}$ where t is the thickness (in millimeters) and β a constant for a particular sample. The base 10 is conveniently used in place of ϵ so that βt becomes the common logarithm of the transmittance, or $\beta t = \log I/I_o$. Using the corrected value of the transmittance for a specific thickness, found in the table, the value of βt may be found, changed to the value for the new thickness and the transmittance for the second thickness computed.

For example: The tabular value of transmission for sample **CG** 396 at $\lambda = .46\mu$ is given as 0.80 for a thickness of 2 mm. It is desired to find the transmittance for 5 mm.

The corrected value of the transmittance for 2 mm is 0.80/.92 or about 0.871. Log .871 = 9.94002–10. Writing this as a wholly negative number the equation becomes $\beta t = -.05998$. For $t = 5$ $\beta t = -.05998 \times 5/2 = -.14995$ or changing to the more familiar form gives 9.85005–10 which is the logarithm of the new transmittance which is found to be .708. The transmission will be .92 × .708 or .651.

In order to identify the glasses listed, the manufacturer's number is given preceded by an abbreviation of the maker's name, as follows: **AO**, American Optical Co.; **BL**, Bausch & Lomb Optical Co.; **CE**, Chicago Eye Shield Co.; **CG**, Corning Glass Works. Data for Jena glasses are given separately in section II of the table.

This table has been compiled with the assistance of: Mr. H. P. Gage, Corning Glass Works; Mr. J. Liautaud, Chicago Eye Shield Co.; Mr. W. B. Rayton, Bausch & Lomb Optical Co.; Mr. A. J. Weinstein of the Fish-Shurman Corporation.

Abbreviations Used

abs., absorbing	lant., lantern	sext., sextant
bl., blue	lt., light	sig., signal
col., colorless	med., medium	tr., transmitting
didym., didymium	neut., neutral	u.v., ultra-violet
dk., dark	purp., purple	v., very
fl., fluorescent	pyrom., pyrometer	viol., violet
grn., green	rd red	yel., yellow
ht., heat		

TRANSMISSION OF COLORED GLASSES

Section I.—Glasses of American Manufacture

Wave-length μ	AO Crown 1.50 neut. 1.68 mm	BL Crookes 1 neut. 2 mm	BL Crookes 2 neut. 2 mm	BL Crookes 3 neut. 2 mm	BL Smoke A neut. 2 mm	BL Smoke B neut. 2 mm	BL Smoke C neut. 2 mm	CG 254 black ht. tr. 1 mm	CG 255 sext. red 1 mm	CG 241 Se red pyrom. 38%
0.22	...	*	*	*	*	*	*	....	....	....
.24	...	....	...	...	...	...	...	....	....	....
.26	...	....	...	...	...	...	...	....	....	....
.28	0	....	...	...	...	...	...	....	....	....
.30	.10	.00	.00	.00	.00	.00	.00	....	....	....
.32	.56	.00	.00	.00	.00	.00	.00	....	....	....
.34	.83	.00	.00	.00	.44	.14	.00	....	....	....
.36	.89	.06	.22	.20	.83	.60	.32	....	....	....
.38	.91	.72	.70	.65	.89	.74	.61	....	0	....
.40	.92	.86	.80	.74	.90	.76	.64	....	.07	....
.42	.92	.89	.78	.54	.85	.70	.43	....	.05	....
.44	.92	.91	.77	.46	.82	.54	.28	....	.015	....
.46	.92	.93	.80	.47	.83	.53	.28	....	.005	....
.48	.92	.94	.82	.51	.84	.55	.33	....	.005	....
.50	.92	.95	.83	.55	.85	.59	.35	....	.000	....
.52	.92	.96	.85	.57	.85	.59	.34	....	.005	....
.54	.92	.97	.86	.58	.85	.59	.33	....	.005	....
.56	.92	.97	.84	.57	.85	.60	.33	....	.015	....
.58	.92	.80	.69	.49	.85	.60	.33	....	.030	....
.60	.92	.99	.85	.58	.85	.59	.32	....	.040	....
.62	.92	1.00	.89	.61	.85	.58	.32	....	.060	0
.64	.92	1.00	.90	.63	.85	.60	.33	....	.070	.067
.66	.92	1.00	.92	.66	.87	.65	.39	0	.090	.503
.68	.92	1.00	.94	.73	.90	.73	.52	.006	.120	.660
.70	...	.99	.97	.90	.95	.88	.75	.012	.150	.667
.72	...	...	...	...	...	...	...	.018	.200	.660
1.0	...	.98	.92	.85	.93	.75	.74	.724	.860	....
1.5	...	.95	.89	.87	.91	.82	.74	.845	.920	....
2.0	...	.94	.89	.83	.90	.81	.72	.812	.920	....
2.5	...	.89	.82	.80	.88	.80	.74	.818	.915	....
3.0	...	.55	.53	.53	.59	.61	.56	.672	.743	....
3.5	...	.31	.25	.33	.35	.33	.31	.549	.670	....
4.0	...	.26	.34	.32	.31	.28	.28	.325	.390	....
4.5	...	.23	.20	.21	.22	.22	.23	.030	....	....
5.0	...	.11	.09	.09	10	.12	.10	....	....	....

Exhibit 3

STAT

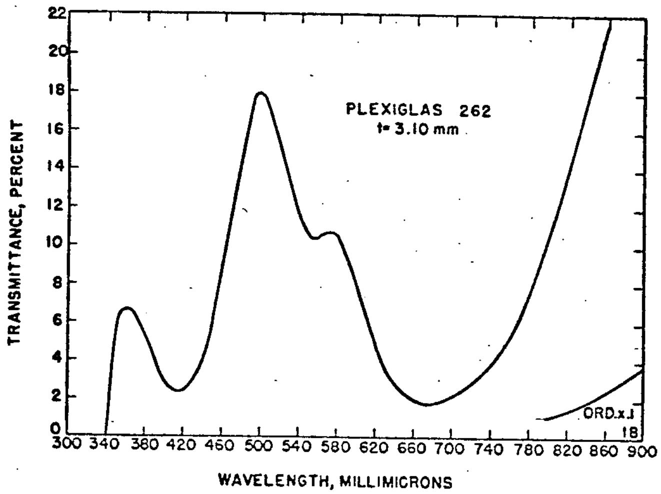

Fig. 42

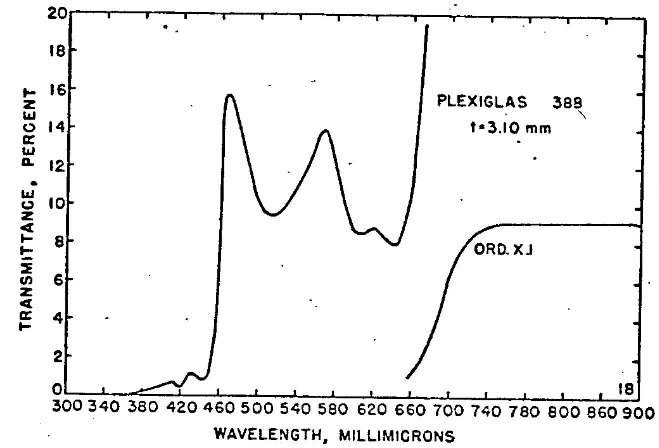

Fig. 43

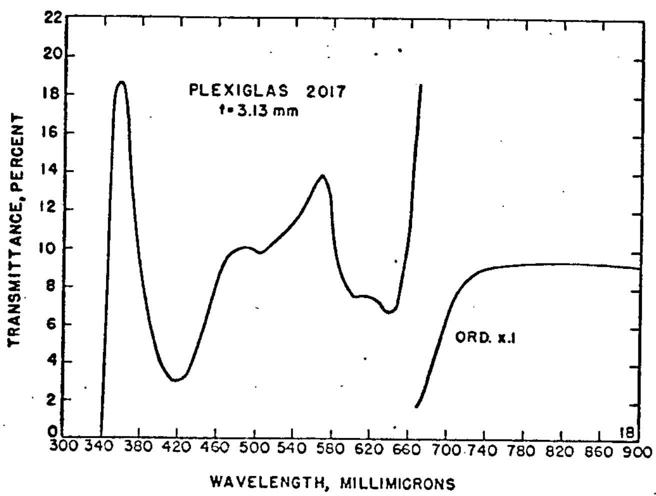

Fig. 44

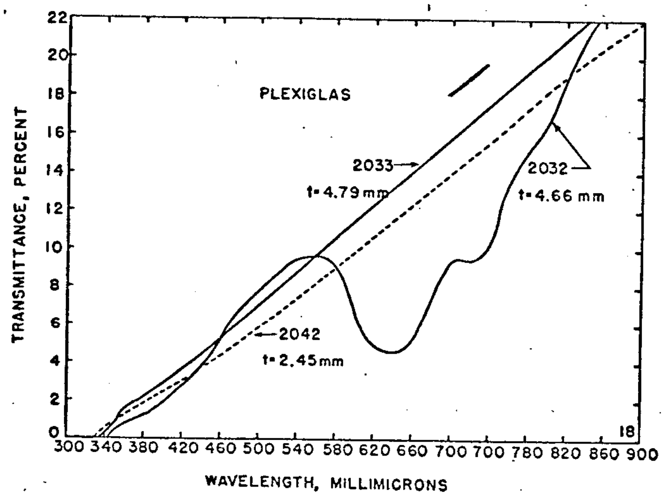

Fig. 45

FOR USE IN EYE PROTECTION

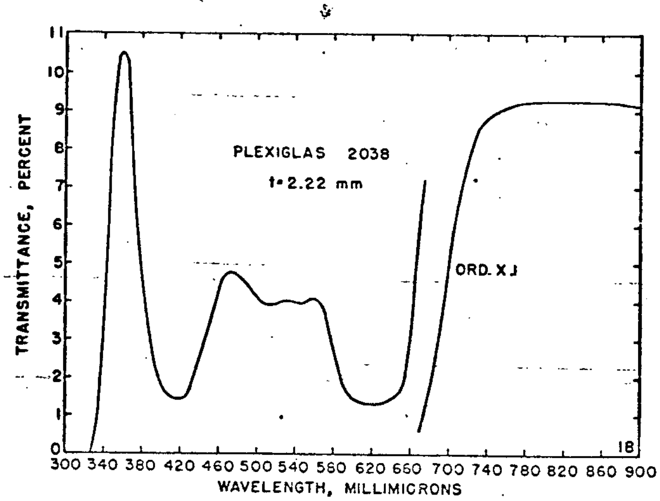

Fig. 46

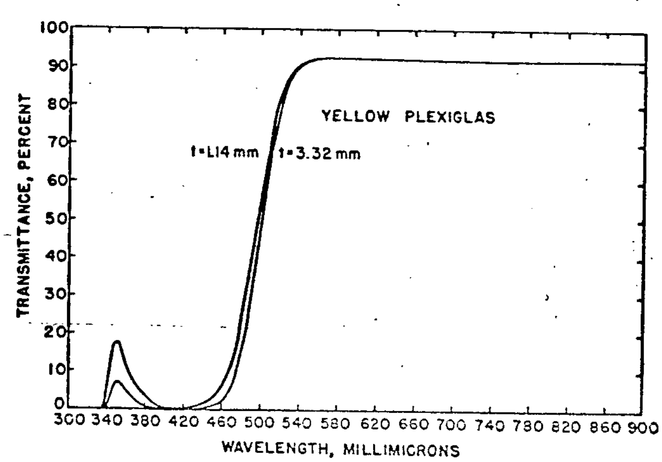

Fig. 47

Exhibit 4

STAT

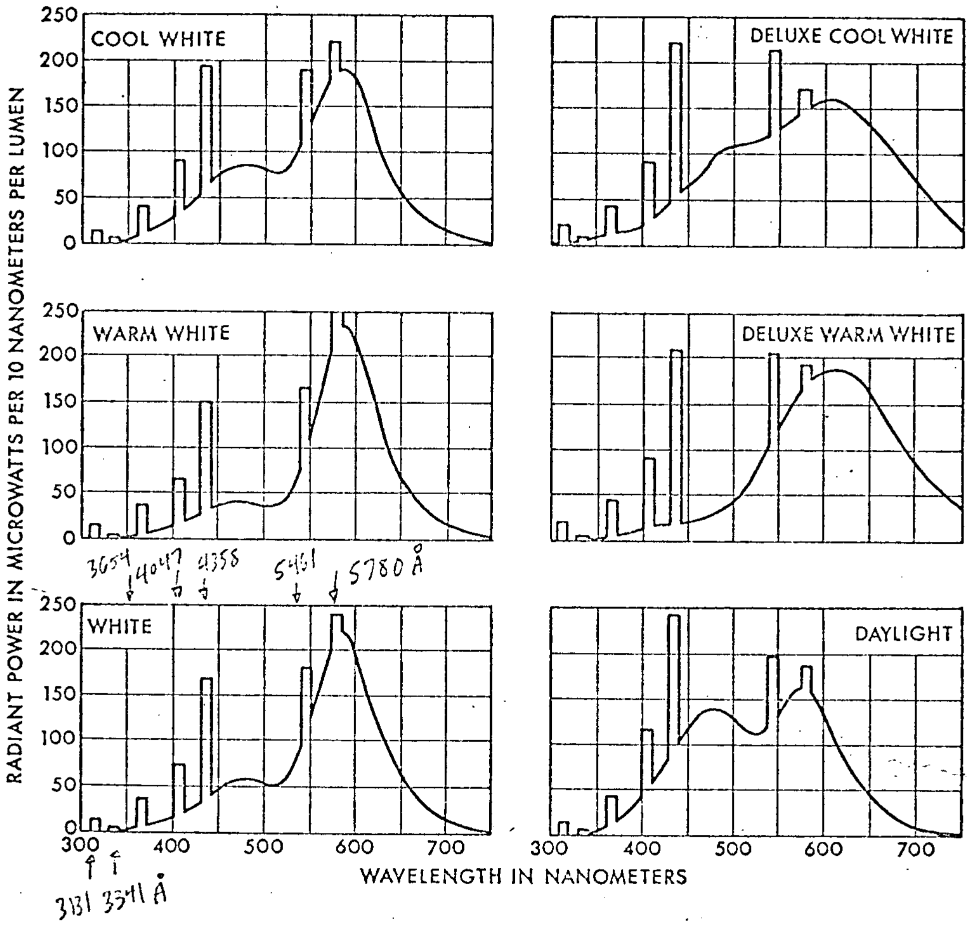

Exhibit 5

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